Engineering Students' Readiness for Self-directed Learning

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Abstract

The study summarized in this paper extends the previous work of the authors that attempted to determine whether capstone engineering courses have an effect on readiness for self-directed learning. The previous study suffered from a poor participation rate and several other potential problems. A new experimental design eliminated these problems. Pre-test and post-test data were collected in two sections of a capstone course in Mechanical Engineering. Results show no statistically significant change in the average pre-test and post-test scores; however, a fraction of the students were found to experience significant increases and decreases. A regression analysis was conducted in an attempt to understand the effect of the characteristics of the students such as gender and grade point average as well as project and section; however, no statistically significant correlation between the change in SDLRS score and any of these factors were found. Interviews with instructors were also conducted and suggested that the decreases in the scores for one project were likely due to the nature of the interactions of the project mentor with the students. Implications of the results of this study for curricular design are discussed.

Introduction

The ABET engineering accreditation criteria bring lifelong learning to the forefront for all engineering educators. In the past, our role in lifelong learning was primarily offering courses and degree programs for practicing engineers through continuing education and on our campuses. Now the accreditation criteria demand that we prepare engineering students to engage in lifelong learning. While this level of emphasis on preparing students for lifelong learning is new, the significance attached to lifelong learning, and in particular continuing education, within the engineering profession is not.

Lifelong learning in engineering has been recognized as critical for decades. The Final Report of the Goals Committee on Engineering Education, written in 1968, contained a discussion of the importance of lifelong learning.[1] In 1978, the theme of the ASEE Annual Conference was "Career Management – Lifelong Learning." Over the years there have been a number of studies to investigate the types of activities involved in lifelong learning, their frequency of use, the types of support systems required for lifelong learning, barriers to lifelong learning, and impact of lifelong learning for individual engineers. Many of these studies are summarized in a 1985 report by an NRC panel.[2]

Lifelong learning is an issue of importance for engineers around the world. UNESCO sponsored several significant studies including "Advances in the continuing education of engineers."[3] The report resulting from this study summarizes practices in continuing education in a number of countries, both developed and developing, and also the delivery systems used. UNESCO played a central role in the formation of the International Society for Continuing Engineering Education in 1986.

Clearly, however, lifelong learning occurs through more channels than just continuing education. In 1986, Cervero *et al.* interviewed nearly 500 engineers by telephone in the area of Rockport, IL.[4] Seventy-two percent of the engineers surveyed were at the BS level and more than one half were under the age of 35. Due to the nature of the businesses in the area, the sample contained predominantly mechanical engineers, 53%, with electrical engineers accounting for an additional 22%. The survey was structured to investigate the participation of the engineers in the three modes of learning proposed by Houle[5] : instruction, inquiry, and performance. Cervero *et al.* summarize these three modes of learning as follows:

> "Instruction is the process of disseminating established skills or knowledge in traditional formats such as formal courses or seminars. Inquiry is the process of creating a new synthesis of ideas, techniques, policies or strategies. … The mode of performance is the process of internalizing an idea or using a practice habitually so that it becomes basic to the way a professional practices." (p. 112)

The authors go on to note that learning is usually a by-product of inquiry, rather than an expected outcome of the process. In terms of frequency of participation, the authors divide their findings into formal (instruction) and informal (inquiry and performance) and note that informal modes are more frequently used, "perhaps because most of these activities are embedded in the daily routines of work."

The formal modes of learning occur in traditional university courses or corporate training and tend to be highly "directed" with the instructor guiding the learning very closely. On the other hand, the informal modes, which occur naturally as part of learning to accomplish work tasks, are much more "self-directed," in that the learner must decide what is to be learned, choose an approach to learning, and manage the learning process independently. On-going work at Penn State has focused on informal/self-directed learning modes. In particular, the work has been directed at identifying curricular approaches to develop the skills and attributes required for lifelong learning. [6, 7, 8, 9] This paper reports the results of a one-group pre-test-post-test administration of the SDLRS for students enrolled in the capstone course in Mechanical Engineering.

Selection of Instrument

In his paper, "Undergraduate Foundations for Lifelong Learning," Flammer [10] proposes a model for successful lifelong learning that has two aspects: motivation and ability. He divided each parameter into two areas. For motivation, these are "won't do" and "will do," and for ability, they are "can do" and "can't do." The successful life long learner was then one who "will do" and "can do." This model emphasizes the two critical factors in lifelong learning: motivation and skills. His discussion and insights are quite consistent with the recent literature on self-directed learning that identifies these same factors. For example, Garrison includes these very same factors, albeit at a more detailed level, in her model for self-directed learning. [11]

Candy, in his extensive review of self-directed learning, summarizes the characteristics of the self-directed learner from many sources. [12] These characteristics fall into two sets, personal attributes and skills, that are analogous to Flammer's "will do" and can do." Candy's lists are:

> "Will do" Attributes: curious/motivated, methodical/disciplined, logical/analytical, reflective/self-aware, flexible, interdependent/interpersonally competent, persistent/responsible, venturesome/creative, confident, independent/self-sufficient.
>
> "Can do" Skills: have highly developed information seeking and retrieval skills, have knowledge about and skill at the learning process, develop and use criteria for evaluating (critical thinking).

A major issue in lifelong learning is how to assess the extent to which students are prepared to engage in it and also their willingness to do so, i.e., Flammer's "can do" and "will do" characteristics of the lifelong learner. Two instruments for assessing lifelong learning are Guglielmino's Self-directed Learning Readiness Scale (SDLRS), developed in 1978, [13] and Oddi's Continuing Learning Inventory (OCLI), developed in 1984. [14] Candy reports that the SDLRS is the much more widely used of the two instruments.[11] During the development of the SDLRS eight factors were identified that contribute significantly to the ability to engage successfully in self-directed learning. These factors were labeled as: openness to learning opportunities, self-concept as an effective learner, initiative and independence in learning, informed acceptance of responsibility for one's own learning, a love to learn, creativity, future orientation, and the ability to use basic study skills and problem-solving skills. Thus, the scale includes factors related to skills and personal attributes required for self-directed learning.

Evidence of reliability and validity for the SDLRS was recently reviewed and summarized.[15] coefficient of internal consistency, based on split-half method and Cronbach's coefficient alpha, is reported to range from 0.67 to 0.96, and test-retest reliability to range from 0.79 to 0.82. The validity of the SDLRS has been studied extensively. Some of the evidence cited in the review of the instrument includes:

- Content validity: strong congruence between Guglielmino's original Delphi results and a review of the literature on self-directed learning. [16]
- Construct validity: Significant convergent and divergent validity found in five different studies.[17, 18, 19, 20, 21]
- Criterion validity: Significant positive correlations reported with learning projects undertaken, [22, 23] with hours spent on self-directed learning,[24] and with observable student behaviors related to self-directed learning.[25]

The review also notes that two papers in the literature criticized the content validity of the SDLRS, [26, 27] but that the criticisms are refuted by other studies. (To put the level of criticism in context it is helpful to note that the SDLRS website[28] lists nearly 200 references in which the instrument was used.) The summary statement from the review of the SDLRS is that it "can be used with acceptable confidence to provide an accurate measurement of readiness for self-directed learning." [15]

Previous Work at Penn State

Two cross-sectional studies were conducted in 2000 and 2002 using the SDLRS with engineering students enrolled at the University Park campus. [8, 9] In the studies, nearly 1000 randomly selected engineering students from semester 1 through 10 were contacted and asked to take the SDLRS instrument on-line. The major research question underlying this study was, "What is the trend in the SDLRS scores across the four years of study?" The desired outcome was that the students' scores would increase as they gain experience in self-directed learning, particularly in the later semesters when students encounter more open-ended problem solving challenges in their elective courses and their capstone experiences. The second research question in the study was whether women and men differ in terms of the change in readiness for self-directed learning. It seems possible that the well-documented differences in men's and women's experiences in engineering classes[29] could lead to some differences in readiness for self-directed learning. To enable the use of the data to address possible gender differences, the random sample of students was balanced for gender.

No statistically significant changes in average SDLRS scores among students in their first through tenth semesters were observed in either of the cross-sectional studies. Thus, the expectation that elective courses and capstone courses would result in enhanced readiness for self-directed learning was not borne out. On the positive side, the study did not show any statistically significant differences between male and female students.

To more explicitly address the hypothesis that the open-ended problem-solving that is required in capstone courses will lead to an increase in readiness for self-directed learning, and therefore in SDLRS score, students taking the capstone courses in Mechanical and Electrical Engineering in Fall of 2002 were asked to take the SDLRS as a pre-test and post-test. To minimize the disruption of the normal flow of these classes, the instrument was provided on-line, and the students were sent an email from their instructors asking them to complete the instrument. Participation in the study was entirely voluntary. The combination of the on-line administration and the voluntary nature of the study led to rather disappointing response rates. Of the 129 students enrolled in the courses, only 24 completed both the pre-test and post-test. The low participation rates raised issues of self-selection bias in the study. For those 24 students, no statistically significant changes were observed.

Current Research

The failure to identify any statistically significant change for students taking the capstone courses was unexpected. Possible problems with the study, especially self-selection bias, led to the decision to undertake another pre-test/post-test administration in two sections of the Mechanical Engineering capstone course. The two sections were taught by different instructors, but both are experienced instructors that are regarded as effective teachers. In an attempt to improve the response rate above the 20% in the Fall 2002 study, a paper form of the instrument was used and it was administered during class. Participation in the study was not part of the course grade, so participation was not guaranteed.

Overall, participation was quite good; 35 of 47 students completed both the pre-test and post-test. The average pre-test score for those 35 students was 223, which was quite consistent with the results from the cross-sectional studies where the seniors had an average score of 226. The samples in the cross-sectional study were randomly selected, so the consistency indicates that the sample in the present study was not biased. The post-test scores of the 35 students had an average of 220, which was not statistically different than the pre-test score *(t=-1.03, d.f.=34, p-value=0.363)*. So, consistent with the earlier pre-test/post-test study and the cross-sectional study, the results suggest that the capstone experience is not affecting the students' readiness for self-directed learning. However, the changes in scores experienced by the individual students reveal a much different picture.

The changes between the pre and post-tests for individual students are plotted in Figure 1 against the pre-test score. This plot reveals that individual students are experiencing substantial changes in SDLRS score concurrent with their experiences in the capstone course. Use of the average score masked the changes that were occurring for the individual students. To determine a 95% confidence interval for the true pre-test scores, a standard measurement error was estimated based on the test-retest reliability coefficients for the SDLRS available in the literature and the sample variance of the pre-test. The test/re-test reliability coefficients of the SLDRS are 0.79 and 0.82. [15] When the lower of the coefficients of reliability is used, the marginal error of a 95% percent confidence interval is $\pm$16 around the pre-test score; indicated by the dashed lines in Figure 1. Thus, a change of more than 16 between the post-test and pre-test scores means that the post-test score can be considered to be different from the pre-test score with 95% confidence.

Figure 1 shows that only four students experienced statistically significant increases in the SDLRS score; while six other students experienced statistically significant <u>decreases</u>. The remainder experienced changes between 16 and -16, which are within the expected confidence interval for test/re-test administration, so the capstone course had no significant effect on their readiness for self-directed learning. It would appear that some of the students are being adversely affected by their experience in the capstone course; in some cases the effects are dramatic. Two students, one from each section, had post-test scores that were more than 40 points <u>below</u> their pre-test scores.

In an effort to understand potential effects of the project on changes in the SDLRS score between the post-test and pre-test, the average change in the team score was plotted versus the average pre-test score of the team. The plot is presented in Figure 2. Two teams have relatively low average pre-test scores. One of these teams showed an average increase of 9 between the pre-test and post-test while the other had a decrease of 9. Of the four teams with average pre-test scores near 224, two show average increases of about 5 and two show average decreases of about 5. Of the two teams with the highest average pre-test scores, one showed no change and the other showed a large average decrease in scores. Interestingly, the instructors both identified this project as having a very demanding mentor, as discussed below.

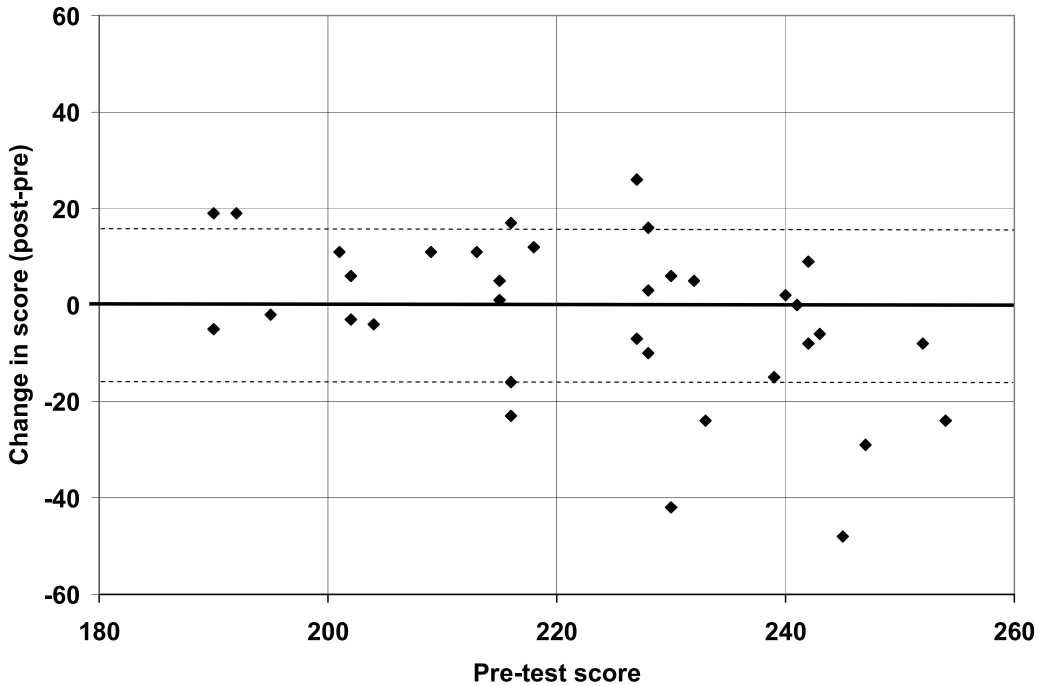


Figure 1. Change in score between pre-test and post-test as a function of pre-test scores.

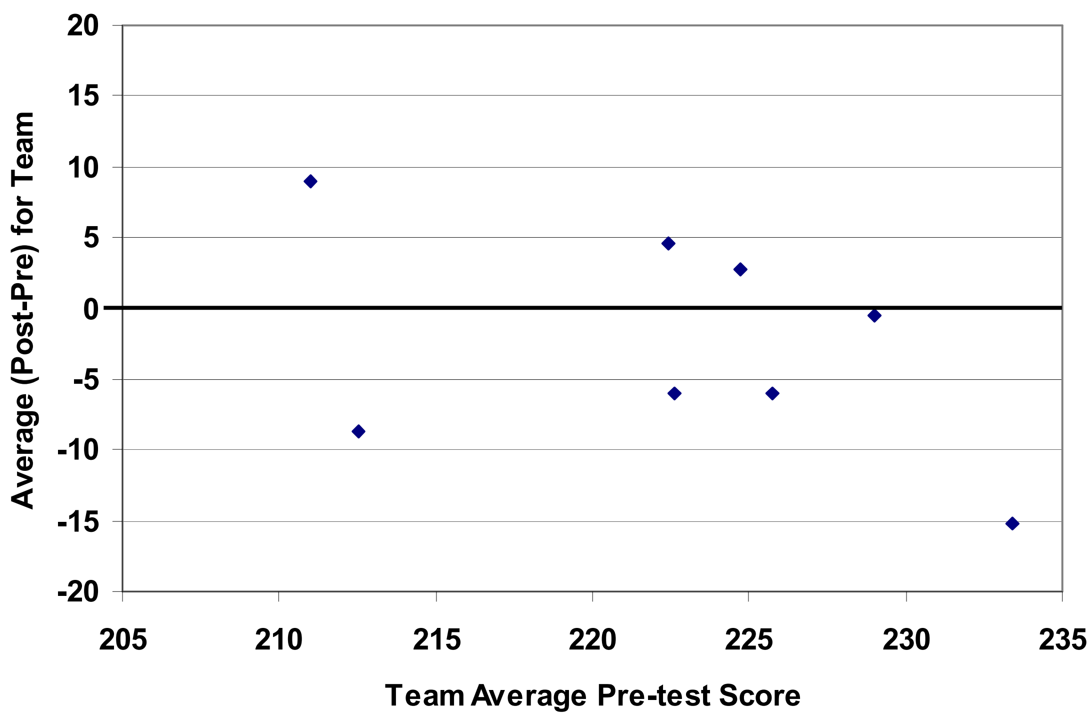
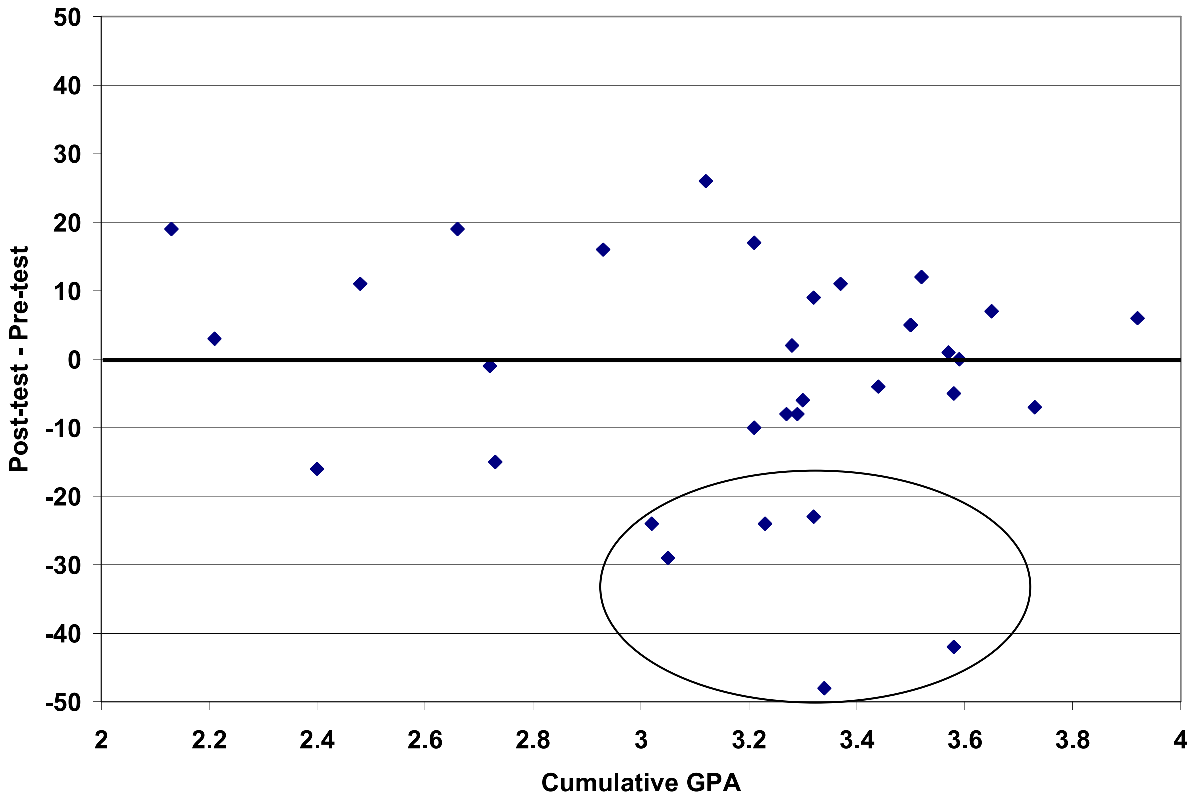


Figure 2. Average change between pre-test and post-test for teams versus average pre-test score

Past research has shown that students who are most comfortable with highly structured learning environments can react adversely when they are asked to perform in unstructured environments.[12] To determine whether this effect might be at play in the current study, changes in scores were plotted against the students' cumulative grade point average (GPA). The students with the largest decreases in scores, inside the ellipse in the figure, have GPA's in the range of 3.0 to 3.6. Their GPA's would indicate that they are fairly successful students in traditional, structured classes, which comprise most of the ME curriculum at this time. It seems possible that their post-test SDLRS scores could have been adversely affected by the unstructured nature of the capstone course. Only interviews with the students can provide support for this conjecture, however.



In an effort to identify possible factors that are leading to the observed changes in individual scores, the difference scores were regressed on the class section, project nested within the section, pretest, gender, cumulative credit, cumulative GPA, the number of coop experiences, interaction term between the pretest and project, and interaction term between the pretest and section. There are two reasons that the model includes only the two interaction terms. First, the sample size is not large enough to test all two-way interaction terms among all variables. Second, the pretest is considered the strongest predictor of the difference score compared with other factors. The test for the model indicates that none of the two-way interaction effects are significant (F=0.71, p-value=0.6519 and F=0.05, p-value=0.8305 each). With the two interaction terms excluded, the difference scores were regressed on the seven variables again. The overall F-test for the seven variables indicates that even though they can account for 44% of the variance of the difference scores, the overall effects are not statistically significant (F=1.24, p-value=0.3247).

Also, the F-test for each variable indicates that neither the project nor the section rise to the level of statistical significance.

In attempt to identify other factors that might have led to changes in SDLRS scores, interviews were conducted with the instructors. During the interviews the instructors were asked the following questions:

a. *Would you please summarize the projects used in the course?*
b. *Were any projects or mentors particularly difficult or frustrating for the students? Were any projects or mentors particularly effective and enjoyable for the students?*
c. *Which projects required the greatest amount of self-directed learning?*
d. *Which students did you feel were best able to handle self-directed learning?*
e. *Which students did you feel were least able to handle self-directed learning?*
f. *Which students did you feel "grew" through the course of the semester? In what ways did they grow?*
g. *Did you notice any students who seemed to be dissatisfied with the project or the course? What did you notice?*

From the discussions with the instructors, one factor came through with clear links to the data. The mentor for one of the projects was identified by both instructors as one who expected too much from the students. The level of interaction and commitment expected by this mentor appeared to have a negative effect on the team. It was this team that had the highest average pre-test score and the largest average decrease from pre-test to post-test. Of the five team members only one had a positive increase in SDLRS score (12); the scores of the other members all decreased. Two of the six students with statistically significant decreases (-24, -43) were on this team. Thus it would appear that the interactions of the students with their mentor had a significant negative effect on the team. The other team that had a large average decrease of 9 points worked on an industrial project that was not noted in any special way by the instructor. However, the instructor did note that the team had one member who was "always on job interviews," which led to problems within the team.

Another interesting connection between the test scores and the data involved the team with the lowest average pre-test score that showed an average increase of 9 points. The project for this team was not from industry, but was an internally generated project that required the students to learn about medieval windmills and to construct a working scale model. Perhaps more than the other projects, this one required the students to learn about new technology on their own. The team chose to make a field trip to see an full-scale medieval windmill in Williamsburg, Virginia. Thus, it appears that the nature of the project can have a positive effect on SDLRS scores as well as a negative one.

Another important finding from the discussions with the instructors about the nature of the projects was that few of them required the students to do much in the way of self-directed learning. Most of the projects involved application of skills and abilities that the students had developed earlier in their studies. Only one project was identified by an instructor as requiring the team to do substantial self-directed learning; it involved acquiring an understanding of an industrial design tool and design software. However, this task was taken up by only one team member, who had a fairly high SDLRS score to begin with. Interestingly the instructor did not note the medieval windmill project as one that required significant amounts of self-directed learning.

Implications for Curricular Design

Based on the results of the study, the only conclusion that can be reached is that the ME capstone course does not lead to any significant increase, on average, in readiness for self-directed learning. The capstone course requires students to work in teams to effect solutions to problems, mostly posed by industrial sponsors. Through the course the students apply many of their technical and non-technical skills as they would in the workplace. However, few of the projects require significant self-directed learning. Thus it would appear that the present curriculum does, on average, little to enhance students' readiness to engage in self-directed learning. Further, the results of the study indicate that assignments and projects aimed at enhancing readiness for self-directed learning must be integrated into the curriculum if students are to make improvements in this important skill.

Previous studies using the SLDRS to investigate the effects of two innovative courses in Industrial Engineering at Penn State indicate the types of experiences that can be effective in increasing SDLRS scores.[8] In an undergraduate two-course sequence, student teams take a product from the concept stage to the manufacturing floor. In this course, lectures are rarely used. Students are challenged to learn what they needed to accomplish their goals, rather than having the instructors deliver all of the information that they might require. The fact that the students are working on their own product concepts may have had a positive influence on their motivation to learn as well. In a second course, at the graduate level, students are asked to "deep read" a technical paper related to the course. The students are given a methodology for deep reading a technical paper and are required to prepare a written evaluation of the paper. The methodology is designed to assist the students in doing an "expert" level review of the paper in order to extract and internalize information of importance to their learning in the course. At a later point in the semester, the students are given additional technical papers related to their course project that they must review and incorporate into their work.

These courses provide just two examples of the types of assignments and pedagogical approaches that are able to enhance readiness for self-directed learning; many others exist in the literature. Thus, what can be done is known, what remains is the task of enhancing engineering curricula to allow students to develop the critical skills and attitudes that are required for self-directed learning.

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